United States Environmental Protection Agency
Research and Development

National Risk Management Research Laboratory
Cincinnati, OH 45268

EPA/600/SR-01/056 November 2001

EPA

Project Summary

Environmental Impacts of the Use of Orimulsion®: Report to Congress on Phase 1 of the Orimulsion Technology Assessment Program

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Orimulsion[1], a bitumen-in-water emulsion produced in Venezuela, was evaluated to provide a better understanding of the potential environmental impacts associated with its use as a fuel. A series of pilot-scale tests were conducted at the U.S. Environmental Protection Agency's Environmental Research Center in Research Triangle Park, NC, to provide data on emissions of air pollutants from the combustion of Orimulsion 100 (the original formulation), Orimulsion 400 (a new formulation introduced in 1998), and a No. 6 (residual) fuel oil. These results, and results of full-scale tests reported in the technical literature, were evaluated to determine the potential air pollutant emissions and the ability of commercially available pollution control technologies to adequately reduce those emissions. Emissions of carbon monoxide (CO), oxides of nitrogen (NO_X), sulfur dioxide (SO_2), sulfur trioxide (SO_3), particulate matter (PM), and organic and metal hazardous air pollutants (HAPs) were measured from each of these three fuels to provide a comparison between the "new" fuel (Orimulsion) and a fuel that has been commonly used in the U.S. (No. 6 fuel oil). Results indicate that CO, NO_X, and PM emissions are likely to be nearly the same as those from the No. 6 fuel oil, that SO_2 emissions can increase if the Orimulsion sulfur content is higher than that of the fuel it replaces, that the particles generated by Orimulsion 100 and 400 are likely to be smaller in diameter than those generated by No. 6 fuel oil, and that HAPs are also likely to be similar to those from No. 6 fuel oil. Both the full-scale results found in the literature and the pilot-scale results measured at EPA indicate that conventional air pollution control technologies can effectively reduce emissions to very low levels, depending upon the type of technology used and the desired emission levels. Because the bitumen in Orimulsion is heavier than water and due to the presence of a surfactant in the fuel, spills of Orimulsion are likely to be more difficult to contain and recover than those of heavy fuel oil, especially in fresh water. Additional study is needed before adequate containment and response approaches can be developed. Little, if any, work has been conducted by the fuel producer or the scientific community to address the remaining spill-related issues.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

[1] Orimulsion is a registered trademark of Bitúmenes Orinoco, S.A.

Purpose and Approach

The purpose of the report is to address the request by Congress that the U.S. Environmental Protection Agency (EPA) "provide better scientific data on the qualities and characteristics of this product [Orimulsion] and the potential environmental impact of its introduction" into commerce. To address this request, a team led by EPA's National Risk Management Research Laboratory (NRMRL) conducted research to examine the potential environmental impacts associated with the use of Orimulsion as a fuel and prepared the report. The EPA research team included Office of Research and Development (ORD) staff from NRMRL, the National Health and Environmental Effects Research Laboratory (NHEERL), the National Center for Environmental Assessment (NCEA), and from the Office of Solid Waste and Emergency Response (OSWER) staff from the Office of Emergency and Remedial Response (OERR).

In response to reviews of Orimulsion research needs by an interagency panel and a panel of external technical experts, EPA prepared an Orimulsion Technology Assessment Plan (OTAP) to guide its research efforts. The reviewers identified the generation and control of air pollutant emissions and the toxicity of those emissions as the key areas of needed research. Orimulsion spill response, containment, and recovery, and the ecological effects of such spills (particularly in fresh water) were considered to be less critical, and could be addressed as needed by the appropriate party or parties. The OTAP outlined a phased approach, with the need for subsequent phases to be determined by any significant questions identified during preceding phases. The report describes the efforts, results, and conclusions of Phase 1 of the OTAP.

The key questions addressed by the report are:

- Are the emissions from the combustion of Orimulsion significantly different from those from other fossil fuels, and if so, how?
- Can the emissions from the combustion of Orimulsion be adequately controlled using existing air pollution control technologies? If not, are there modifications to existing technologies that can be made to adequately control emissions, or are new control technologies required?
- Is the behavior of Orimulsion during a spill significantly different than that of other fossil fuels, and if so, how?
- What gaps exist in understanding the behavior of Orimulsion based on the behavior of other fossil fuels and the known properties of Orimulsion? Are these gaps serious with respect to understanding the potential environmental impacts, and if so, what research should be conducted to address these gaps?

To address these questions, ORD staff conducted a thorough literature review, visited several full-scale power plants that used Orimulsion as their primary fuel, conducted pilot-scale combustion tests, tested measures of pulmonary toxicity of PM generated by Orimulsion combustion, and carried out an independent review of an assessment of environmental risks associated with Orimulsion use. The report discusses the methods and results of these efforts and draws conclusions based on those results.

Background

Orimulsion is a liquid fossil fuel consisting of an emulsion of approximately 70% bitumen (a naturally occurring heavy petroleum material) from the Orinoco region of Venezuela, approximately 30% water, and a small amount of surfactant. The fuel consists of small (8-24 µm diameter) droplets of bitumen emulsified in water and the surfactant. Orimulsion is produced by Bitúmenes Orinoco, S.A. (Bitor), a subsidiary of the Venezuelan national oil company Petróleos de Venezuela, S.A. (PDVSA), and derives its name from the combination of "Orinoco" and "emulsion."

In recent years, Orimulsion has been proposed as a fuel to replace either coal or heavy fuel oil in utility power plants throughout the world. Orimulsion is currently being used as the primary fuel at nine power plants in Canada, Denmark, Italy, Japan, and Lithuania, representing 3,866 MW of electric power generating capacity and approximately 7.5 million tons of fuel consumption per year. To date, no plant in the U.S. has used the fuel for other than short-term testing.

Air Emissions

Available technical literature (24 references describing air pollutant emissions at 9 full-scale sites and 3 pilot-scale facilities) was reviewed to determine the problems and issues believed to be most important with respect to air pollutant emissions and control and to evaluate the levels of emissions experienced by full-scale systems using Orimulsion. Table 1 summarizes data reported in the literature for Orimulsion and heavy fuel oil. SO_2 and PM data are for pollutant concentrations upstream of any control device.

The reports indicated that CO emissions could be easily controlled by increasing combustion air levels. In general, the conventional techniques used to reduce NO_x emissions from oil combustion (staged combustion, reburning, selective catalytic reduction) were reported to be applicable to Orimulsion. CO and NO_x were dependent upon boiler oxygen (O_2) and the combustion system design, similar to other fossil fuels. SO_2 concentrations from Orimulsion [upstream of any flue gas desulfurization (FGD)] were consistent with SO_2 concentrations from other fuels with similar sulfur contents. The literature reported that conventional FGD systems could remove up to 95% of SO_2 generated by the combustion of Orimulsion. This would result in controlled emissions of approximately 125 ppm. Full-scale results demonstrated that electrostatic precipitators can be used to control PM emissions to a level similar to those of other fossil fuels.

Emissions of HAPs were similar for both Orimulsion and fuel oil. For both fuels, volatile and semivolatile organic compounds were found in very low quantities and would not be likely to be near the 10-ton/year level specified in Title III of the Clean Air Act Amendments of 1990. Due to the elevated levels of metals in Orimulsion, metal emissions were higher than organics, with nickel (Ni) and vanadium (V) being found in the highest concentrations. Although V is not listed as a HAP under Title III, it is of concern because of its potential for causing acute pulmonary damage when inhaled. Ni concentrations in Orimulsion flue gas were higher than those from heavy fuel oil, but both iron and zinc concentrations were higher in heavy fuel oil flue gases than in those from Orimulsion. Processes have been designed to allow recovery of Ni and V in Orimulsion. At least two plants are currently sending Orimulsion ash to facilities for recovery of one or both metals, thereby reducing solid waste streams.

Data From EPA Pilot-scale Tests

Two formulations of Orimulsion (one commercially available and one discontinued) and a No. 6 fuel oil were individually tested in a pilot-scale combustor at EPA's Environmental Research Center to allow direct comparison of emissions. Concentrations of CO, nitrogen oxide (NO), SO_2, SO_3, and PM were measured, as were concentrations of volatile and semivolatile organic compounds and metals. Measurements of emissions from the different fuels were compared to determine any differences in the amount or character of emissions. The tests were

Table 1. Summary of air pollutant concentrations reported in the literature for Orimulsion and heavy fuel oil. (SO_2 and PM values are upstream of any control device.)

Pollutant	Literature Data	
	Orimulsion[1]	Heavy Fuel Oil
CO	30-100 ppm[2] (4 tests)	30-100 ppm (4 tests)
NO_x	80-400 ppm (10 tests)	180-420 ppm (6 tests)
SO_2[3]	2500 ppm	1200 ppm[4]
SO_3[5]	2-15 ppm (6 tests)	4-12 ppm (2 tests)
PM[3]	160-350 mg/Nm^3 (8 tests)	100-415 mg/Nm^3 (4 tests)
PM size	98-100% <10µm 80-97% <1µm	75-87% <10µm 45-51% <1µm

[1] Most data reported in the literature are for Orimulsion 100, although there are several data points for Orimulsion 400.
[2] Concentrations of all pollutants are as measured and are not corrected to account for differences in O_2 concentration.
[3] Concentrations are measured upstream of any control device.
[4] No SO_2 values for fuel oil were reported in the Orimulsion literature. The 1200 ppm value is calculated based on 2% sulfur in the fuel. SO_2 concentrations are strongly dependent upon the amount of sulfur in the fuel.
[5] Measured using mini acid condensation sampling (MACS) method.

conducted following NRMRL Quality Assurance Level II procedures, which included audits of measurement equipment and reviews of data by outside organizations.

EPA's pilot-scale results were similar to those reported in the literature in terms of comparison of Orimulsion to heavy fuel oil, with data showing little difference in CO, NO_X, or PM furnace exit concentrations, and smaller particles for Orimulsion than for heavy fuel oil. The pilot-scale data differed most from the full-scale data for NO_x, but were not unreasonable given the difference in combustor system design. The pilot-scale tests provided further valuable confirmation of the similarity between Orimulsion and heavy fuel oil, and also generated samples for use in pulmonary toxicity testing.

Toxicity Testing

NHEERL conducted tests measuring the pulmonary toxicity in laboratory animals of PM generated by the combustion of Orimulsion 100, Orimulsion 400, and No. 6 fuel oil. Laboratory rats were exposed by intratracheal instillation of different doses of PM from each of the fuels burned in the NRMRL combustion tests, as well as Arizona road dust (ARD) and a saline solution. Five biomarkers of pulmonary toxicity or injury [bronchial alveolar fluid (BALF) neutrophil/mL, BALF protein, albumin, lactate dehydrogenase (LDH), and eosinophil/mL] were measured at 24 hours post-exposure. Each sample was ranked according to its lowest observed effect level (LOEL) for each of the five biomarkers. The relative toxicity rankings for each biomarker were:

BALF protein: No. 6 fuel oil > Orimulsion 400 ≥ Orimulsion 100 > ARD = Saline
albumin: No. 6 fuel oil ≥ Orimulsion 100 ≥ Orimulsion 400 > ARD = Saline
LDH: Orimulsion 400 > Orimulsion 100 = No. 6 fuel oil =ARD = Saline
neutrophil: Orimulsion 100 = Orimulsion 400 = No. 6 fuel oil = ARD > Saline
eosinophil: Orimulsion 100 = Orimulsion 400 = No. 6 fuel oil > ARD > Saline

The conclusion drawn by the toxicity tests is that, under the combustion conditions employed in these studies, both Orimulsion formulations generated PM emissions that were capable of producing significant adverse acute pulmonary toxicity. In addition, PM derived from the combustion of Orimulsion 100 and Orimulsion 400 was found to be very similar to No. 6 fuel oil fly ash particles in its ability to induce acute pulmonary toxicity. Different results are possible for PM from full-scale units with different operating conditions, for animals exposed via direct inhalation rather than instillation, or for health-compromised animals.

Spills

Orimulsion is considered to be a "non-floating" oil and is classified as a "non-petroleum oil" by EPA's Office of Solid Waste and Emergency Response. Once spilled, the bitumen fraction of Orimulsion is likely to either sink or remain neutrally buoyant, rather than forming a coherent surface slick. Special equipment is required to effectively contain and recover Orimulsion spills in saltwater environments, and such equipment is currently used at shipping terminals where Orimulsion is off-loaded.

Data gaps remain in understanding the behavior and fate of Orimulsion spilled in fresh water. However, as noted in the OTAP, if Bitor does begin to develop U.S. customers at a site accessible only by fresh water, at a site near bodies of fresh water, or at a site where fresh water can be contaminated by a spill, even indirectly, Bitor should be responsible for the research to address the data gaps as they have done for marine environments. Such research does not fall under the Congressional directive for this report and should not be considered to be EPA's responsibility under that directive. However, since EPA is responsible for responding to spills in certain situations, the Agency should continue to investigate Orimulsion spill behavior and response as appropriate. EPA, in collaboration with the U.S. Coast Guard, has requested the National Academy of Sciences (NAS) to conduct a study on Orimulsion to evaluate what additional information is required to effectively respond to freshwater spills. EPA is currently conducting smaller studies on Orimulsion characteristics and on spill behavior modeling and will address the data gaps identified by the NAS, as appropriate. EPA should remain aware of any research conducted by others regarding freshwater spills.

Risk Assessment

The potential ecological risk associated with the use of Orimulsion was evaluated by a panel of independent reviewers chosen by EPA, who examined the detailed work carried out by Bitor to estimate the ecological risk associated with a potential spill in the Tampa Bay, FL, marine environment. The Bitor study compared a hypothetical spill of Orimulsion 100 to a hypothetical spill of an equal volume of heavy fuel oil. The comparative assessment examined transport and fate of both fuels, including potential effects on shorelines and aquatic biota under a range of different spill locations, seasonal variations, and wind and current conditions.

The independent reviewers agreed with the major conclusion of the Bitor study that a spill of Orimulsion 100 likely poses a similar or lower risk to Tampa Bay biota than does an equivalent spill volume of No. 6 fuel oil. However, the reviewers noted that parts of the assessment, such as risk characterization, population modeling, and impacts to benthic communities, were identified as assessment topics that could be improved. The reviewers felt that these improvements would enhance the Tampa Bay report, but did not feel that the improvements would impact the report's conclusions.

A study of cancer risk associated with air emissions from the combustion of heavy fuel oil in electric utility steam generating units was used as the basis for comparing cancer risks due to the use of Orimulsion with those from the use of heavy fuel oil. The original study evaluated the risk to human health associated with exposure to HAP emissions from electric utility steam generating units and estimated that 0.4 additional incidences of cancer would be caused by exposure to Ni emissions from all 137 oil-fired plants in the U.S. This value was considered to be a conservative estimate of the potential cancer risk associated with the use of Orimulsion, based on the Ni emissions from both fuels.

Potential Use of Orimulsion

Orimulsion can be used in applications similar to coal or heavy fuel oil. Orimulsion is readily used in plants designed to use heavy fuel oil, due to the fuels' similar handling and use characteristics, although substantial changes to fuel storage and handling equipment, air pollution control systems, and boiler internal components may be required. The difference in fuel prices between fuel oil and coal may also favor fuel oil as being more likely to be replaced with Orimulsion. The states with the highest fuel oil use are (in order of amount used) Florida, New York, Massachusetts, Connecticut, and Hawaii, all of which are oil consumers and not oil producers. They are also located on the coast and may be more suitable markets for Orimulsion than states with high coal consumption.

Conclusions of the Report

- Orimulsion is physically and chemically an emulsified heavy fuel oil with elevated sulfur, V, and Ni content.
- Emissions of air pollutants from Orimulsion are not significantly different in character from those from other fossil fuels. Orimulsion will, in general, emit more pollutants than natural gas, about the same as heavy fuel oil, and less than pulverized coal. These comparisons do not hold for all cases and are based on emission levels without air pollution control systems.
- Results from both full- and pilot-scale tests indicate that emissions from the combustion of Orimulsion can be adequately controlled using commercially available air pollution control technologies.
- Conversion of a plant to use Orimulsion may require significant changes to fuel supply and handling and air pollution control equipment and modifications to boiler internal components.
- In general, Orimulsion generated PM emissions that were capable of producing significant adverse acute pulmonary toxicity, very similar to the No. 6 fuel oil tested. In all cases, PM from both Orimulsion formulations and the No. 6 fuel oil showed measures of toxicity greater than or equal to either ARD or saline solution.
- The behavior of Orimulsion in a spill is significantly different than that of most other fossil fuels.
- A review by an EPA-chosen expert panel of a Bitor-funded ecological risk assessment of a potential spill in the Tampa Bay, FL, marine environment agreed with the assessment's conclusion that a spill of Orimulsion 100 likely poses a similar or lower risk to Tampa Bay biota than does an equivalent spill volume of No. 6 fuel oil.
- The most likely use of Orimulsion in the U.S. in the short term is as a replacement for heavy fuel oil, due to similarity in handling and combustion properties, the price differential between the two fuels, and the readiness of plants using heavy fuel oil to accept tanker shipments of Orimulsion. These factors would indicate that Orimulsion is most likely to be used along the Atlantic and Gulf coasts in the U.S.
- The major gaps in understanding Orimulsion behavior are in freshwater spill response and effects. Further work in this area should primarily be the responsibility of the fuel's suppliers and users and should not be considered as part of the Congressional directive to provide improved scientific information on the environmental impacts of Orimulsion use. EPA should continue to evaluate spill effects, behavior, and response, as appropriate, in support of their legislated responsibility for spill response.

Recommendations of the Report

The following recommendations are made with regard to Orimulsion behavior, its potential environmental impacts, and EPA's role in further studies:

1. Based on the results of Phase 1 of the OTAP, it is not necessary for EPA to proceed with Phases 2 and 3.
2. From the perspective of air pollutant formation and control, Orimulsion should be considered to be a heavy fuel oil, albeit with some properties that require special attention.
3. Studies of Orimulsion behavior in freshwater spills are needed in the event that Orimulsion is transported along fresh waterways or used in situations where spills can reach fresh water, even indirectly. This research should evaluate the behavior and effects of Orimulsion under different conditions (water density, presence of silt or other solids, energy level of waves) and should evaluate means of containing and responding to spills. Bitor or the end user should be responsible for the cost of any such work that directly supports efforts to market Orimulsion in the U.S. EPA should continue to follow any work conducted by others on the behavior and fate of Orimulsion spills and should conduct the research necessary to support their legislated responsibility for spill response, outside the scope of the Congressional directive to provide improved scientific information on the environmental impacts of Orimulsion use.
4. Research recommended in a review by an EPA-chosen panel of a Bitor-funded ecological risk assessment of a potential spill in the Tampa Bay, FL, marine environment is considered to be the responsibility of Bitor.

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The complete report, entitled "Environmental Impacts of the Use of Orimulsion®; Report to Congress on Phase 1 of the Orimulsion Technology Assessment Program; Volume 1: Executive Summary, Report, and Appendix A," and "Volume 2: Appendices B-H," will be available at http://www.epa.gov/ORD/NRMRL/Pubs or from:

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